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RESEARCH MEMORANDUM

THE EFFECT OF AIR-JET AND STRIP MODIFICATIONS ON THE

HYDRODYNAMIC CHARACTERISTICS OF THE STREAMLINE

FUSELAGE OF A TRANSONIC AIRPLANE

By

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and Charles L. Shuford, Jr.

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THE EFFECT OF AIR-JET AND STRIP MODIFICATIONS ON THE

HYDRODYNAMIC CHARACTERISTICS OF THE STREAMLINE

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SUMMARY

Specific free-to-trim tests were made on a $\frac{1}{12}$-size model of a streamline fuselage modified by patterns of air jets or strips on the fuselage bottom. The effects of spacing of jets, length of jet rows, and direction of jets were determined for a simulated chine configuration. Tests were also made of a simulated multiple-step configuration. The effect of air flow on both the chine and step configurations was studied. In addition, the effect of substituting narrow breaker strips for the rows of jets in the chine configuration and in three multiple-step configurations was investigated.

Data are presented on resistance, trim, effective hydrodynamic lift, and spray. The resistance was reduced by decreasing the jet spacing, increasing the length of rows of jets, and increasing the air flow. In the chine configuration, the strips gave about the same results as the $\frac{1}{4}$-inch-spaced jets. Strips in the form of multiple V-steps pointed forward gave the highest resistance and strips in the form of multiple V-steps pointed aft resulted in the lowest resistance of all the jet and strip configurations tested.

INTRODUCTION

When a fuselage having a circular or oval cross section moves along a water surface at high speeds, the water flowing up around the convex bottom and sides of the fuselage creates a suction force which keeps the hull low in the water and causes a large hydrodynamic resistance which increases rapidly with speed. Results reported in reference 1 showed that the very high hydrodynamic resistance was greatly reduced when air was ejected at high velocity through fine jets in the fuselage bottom. In that investigation various patterns of jets simulating chines and multiple steps were explored.

In the present investigation, the effects of spacing of jets, length of jet rows, direction of jets, and amount of air flow on the hydro-dynamic characteristics were determined for one of the better chine con-figurations of reference 1. Jets in the form of V-steps pointed forward were also investigated for a closer jet spacing than that used in reference 1. The effects of substituting narrow breaker strips for the rows of jets in the chine configuration and for the rows of jets in the three multiple-step configurations reported in reference 1 were also investigated.

DESCRIPTION OF MODEL

The model was a $\frac{1}{12}$-size model of the streamline fuselage of a hypo-thetical transonic airplane (see figs. 1 and 2) and was the same model described in reference 1. The center of gravity was located 0.43 inch below the center line at station 21.22. (Distances from the nose measured along the center line are designated as stations.) The length of the model was 42.22 inches and the maximum diameter was 5 inches.

Stainless-steel tubes of 0.026-inch inside diameter and spaced 1/4 inch apart were inserted into the bottom of the model in rows simulating chines as shown in figures 1 and 2(a). Two sets of tubes were inserted; one in which the tubes were perpendicular to the center line and one in which they were slanted aft at an angle of 45°. A plan view of these simulated chine configurations is shown in figure 2(a). Additional rows of perpendicular jets were inserted to form the pattern simulating the multiple steps shown in figure 2(b). These jets were also spaced 1/4 inch apart.

The basic model was also modified by $\frac{1}{16}$-inch wide strips of tri-angular cross section arranged in all the patterns shown in figure 2. The size of the strips relative to the model is shown in figure 3.

Two types of strips were arranged in each multiple-step pattern. In one type, the forward side of the strip was perpendicular to the surface of the fuselage with the hypotenuse of the cross section forming the after side; in the other type, these conditions were reversed.

Figure 2 shows the multiple-step configurations arranged as eight V-steps pointed forward, as eight V-steps pointed aft, and as nine transverse steps having no V-angle.

APPARATUS AND PROCEDURE

The tests were conducted in Langley tank no. 2. The model was arranged on the staff of the towing gear as shown in figure 4. The model was supported at the center of gravity and towed free to rise and free to trim between 0° and 20°. A dashpot was used to damp out oscillations in trim. The load on the water was varied with speed assuming a constant aerodynamic lift coefficient for a hypothetical wing. Measurements were taken of resistance, trim, and rise at constant speeds up to 60 feet per second. The effective hydrodynamic lift was calculated by subtracting from the load on the water the static buoyancy corresponding to the immersed volume of the model at rest for the trim and rise measured when up to speed. No data are presented between 60 feet per second and the assumed take-off speed of 70 feet per second, because at these speeds practically all of the model was out of the water and slight variations in wetted surface caused the readings to become erratic.

The average air flow per jet for the jet configuration was 11×10^{-5} pounds per second (0.055 lb/sec, full-size) except when varied for a few representative speeds to determine the effect of air flow on resistance. The full-scale air flow was computed by dimensionally scaling up the model air flow assuming that all forces varied in the same way as the gravitational forces.

The jets perpendicular to the center line and arranged in rows simulating chines extending from station 10 to the aft end of the model, were tested with jet spacings of 2 inches, 1 inch, 1/2 inch, and 1/4 inch. The $\frac{1}{4}$-inch-spaced jets were also tested for three other lengths extending from the after end of the fuselage forward to stations 18, 26, and 34. The jets slanted aft and arranged in rows simulating chines and the rows of jets simulating multiple steps were tested with the $\frac{1}{4}$-inch spacing.

Strips simulating chines were tested for the same lengths as the rows of jets. Strips placed in the multiple-step configuration were tested for V-steps pointed forward, V-steps pointed aft, and transverse steps.

RESULTS AND DISCUSSION

Basic or Unmodified Model

The resistance, trim, and effective hydrodynamic lift of the basic or unmodified model are shown in figure 5. (See reference 1.) The resistance increased rapidly to 19.5 pounds at 40 feet per second with

no indication of any reduction in the rate of increase. The trim quickly
rose to 18.6° at 17 feet per second and then remained against the trim
stops (set at 20°) from 25 feet per second up. The effective hydro-
dynamic lift was very low. The low lift and the high trim are an indi-
cation of the strong suction forces acting on the unmodified fuselage.

Effect of Jet Spacing

The effect of jet spacing on resistance, trim, and lift are shown in
figure 6. The resistance and trim decreased as the jet spacing was
decreased but were always considerably less than for the basic model.
The lift was practically the same for all spacings except at 15 and 22 feet
per second.

The lower trims obtained for the more closely spaced jets indicate
that they reduced the suction forces more than the jets spaced further
apart. The presence of some suction force for all jet spacings was
shown by the model maintaining a trim of at least 6° at the higher speeds
even though the center of gravity was forward of the wetted area.

The photographs in figure 7 show the spray characteristics of
the 2-inch spacing and the $\frac{1}{4}$-inch spacing at 35 feet per second. At
this speed the trim for the 2-inch spacing was about 2° higher than for
the $\frac{1}{4}$-inch spacing. The spray height was about the same for both, but
the density of the spray was less for the $\frac{1}{4}$-inch spacing. The direction
of the spray at the side of the model was more nearly vertical for

the 2-inch spacing than for the $\frac{1}{4}$-inch spacing. The jets caused the
spray to separate from the fuselage and the $\frac{1}{4}$-inch-spaced jets were
apparently more effective in this respect than the 2-inch-spaced jets.

Effect of Length of Jet Rows

Results of tests to determine the effect of varying the length of
the rows of jets simulating chines are given in figure 8. The resistance
was decreased with an increase in length of the jet rows. Because the
curves for the 24- and 32-inch lengths are practically the same, no
further reduction in resistance could be expected if the rows of jets
were extended to the nose of the fuselage. The omission of the forward
portion of the simulated chines, however, permitted the water to run up
over that part of the fuselage at low speeds.

The trim and lift for the 16-, 24-, and 32-inch lengths were practically the same. The resistance for the 16-inch length, however, was greater than for the other two.

The difference in spray characteristics between the 8-inch length and 32-inch length is shown in figure 9. The spray for the 8-inch length was heavier than that for the 32-inch length. The arrow in the photograph of the 8-inch length points to station 34 at which a spume of spray comes off the forward jet. The water forward of this station can be seen running up the side of the model with some of the water going over the top; the spray aft of station 34 slants back in a more nearly horizontal direction. For the 32-inch length, the spray broke from the model along the entire wetted length and the top of the model was free of water.

Effect of Slanting Jets Aft

The effect on resistance, trim, and lift of substituting chine jets slanted back at an angle of 45° to the center line for jets normal to the center line is shown in figure 10. The substitution of slanted jets for jets perpendicular to the center line had little effect on resistance or lift but increased the trim over most of the speed range. The horizontal thrust component of the slanted jets, measured at rest with a load on the water of 7.6 pounds, was about 0.1 pound.

The photographs in figure 11 compare the spray pattern of the slanted jets with that of the normal jets in the chine configuration. The upper surface and the stern of the model with the slanted jets was completely free of water as shown in figure 11(c). The spray characteristics of the model with the jets perpendicular to the center line were similar.

Effect of Air Flow

The curves in figure 12 show the effect of air flow on resistance at three representative speeds for each of three different configurations. The jet spacing for all three configurations was 1/4 inch and the number of jets in each was approximately the same.

The variation in resistance with air flow at each speed was approximately the same for all three configurations. The very high resistance at extremely low air flows shows that merely venting the bottom of the fuselage through the jets would have had little effect on the resistance. As the average air flow per jet was increased, the resistance was reduced at a decreasing rate until at flows greater than 11×10^{-5} pounds per second the resistance remained practically

constant. An average air flow per jet of 11×10^{-5} pounds per second through the rows of $\frac{1}{4}$-inch-spaced jets would amount to a total of about 14 pounds per second in the full-size hypothetical airplane (neglecting scale effect).

Comparison of Rows of Jets and Strips Simulating Chines

The strips (less than 2 percent of the maximum fuselage diameter) like the jets were intended as spoilers to cause separation. A comparison between the results for rows of jets simulating chines and the results for strips placed at the same location as the rows of jets is given in figure 13. The trim, resistance, and lift curves for the two modifications were practically the same. The strips also gave results substantially the same as the jets for other chine lengths. Figure 14 shows that the spray off the strips was much cleaner and did not rise as high as that for the jets.

Comparison of Rows of Jets and Strips Simulating Multiple Steps

In contrast to the results obtained when strips were substituted for rows of jets simulating chines there was no correlation between the results obtained when strips were substituted for rows of jets simulating steps. As shown in figure 15, the resistance and trim for the strips with V-steps pointed forward were very much higher than for $\frac{1}{4}$-inch-spaced jets in the same configuration; they were even higher than for the basic model. This jet configuration was the best of the three jet configurations simulating multiple steps reported in reference 1.

Figure 16 shows the results obtained with strips arranged in all three of the multiple-step configurations described in reference 1. The forward side of each individual strip is the hypotenuse of the 45° right triangle forming its cross section. The very high resistance for the V-steps pointed forward was not obtained with the other two step configurations. The maximum resistance for the V-steps pointed aft was about 2.5 pounds at 15 feet per second and the resistance never exceeded 2 pounds at the higher speeds. This configuration was a considerable improvement over the strips simulating chines for which the maximum resistance was about 4 pounds at 50 feet per second. No readings for the transverse steps were taken at speeds above 40 feet per second because the model became unstable.

The trim for the V-steps pointed aft reached a maximum of about 8° and dropped rapidly above 25 feet per second reaching a minimum of about 1° at 55 feet per second. The trim track for the transverse strips was similar.

When the strips were used in the form of V-steps pointed forward, the after half of the model was sucked under and a large amount of spray was thrown out to either side. The spray characteristics for the V-steps pointed aft were about the same as for the chine strips; only a small amount of spray was thrown out in an almost horizontal direction.

When the hypotenuse formed the after side of each strip and the forward side was perpendicular to the fuselage bottom, the results obtained were nearly the same as shown in figure 16 although the resistance was generally slightly higher.

Results reported in reference 1 showed similar hydrodynamic characteristics among the three multiple-step configurations when jets were used. When strips were substituted for jets in these multiple-step configurations the V-steps pointed forward gave results entirely different from the other two. It appears that the effect of strips on the hydrodynamic characteristics of the fuselage was more dependent on the configuration used than was the effect of jets.

CONCLUSIONS

The results of model tests to determine the effect of various jet and strip modifications on the hydrodynamic characteristics of a streamline fuselage indicate the following conclusions:

1. The resistance was decreased as the jet spacing was decreased or the length of the jet rows simulating chines was increased.

2. Substitution of chine jets slanted 45° aft for jets normal to the center line increased the trim but had little effect on the resistance.

3. As the average air flow per jet was increased, the resistance was reduced at a decreasing rate until at flows greater than 11×10^{-5} pounds per second the resistance remained practically constant.

4. In the chine configuration, strips protruding less than 2 percent of the maximum fuselage diameter gave about the same resistance and trim as rows of $\frac{1}{4}$-inch-spaced jets, but the spray characteristics for the strips were better.

5. With similar strips arranged as V-steps pointed forward, the resistance and trim were very high. For V-steps pointed aft, the resistance and trim were considerably lower than for either strips or jets in the chine configuration.

Langley Aeronautical Laboratory
    National Advisory Committee for Aeronautics
        Langley Air Force Base, Va.

<center>REFERENCE</center>

1. Weinflash, Bernard: The Effect of Air Jets Simulating Chines or
    Multiple Steps on the Hydrodynamic Characteristics of a Stream-
    line Fuselage. NACA RM L8J21, 1948.

CONFIDENTIAL

Normal jets

Slanted jets

Sta. 41.00

.026 D. tubes

Centerline

Jet outlets

Sta. 38.50

45°

45°

$\frac{1}{4}$

$\frac{1}{4}$

NACA

Note:
    All dimensions in inches model size, feet full size
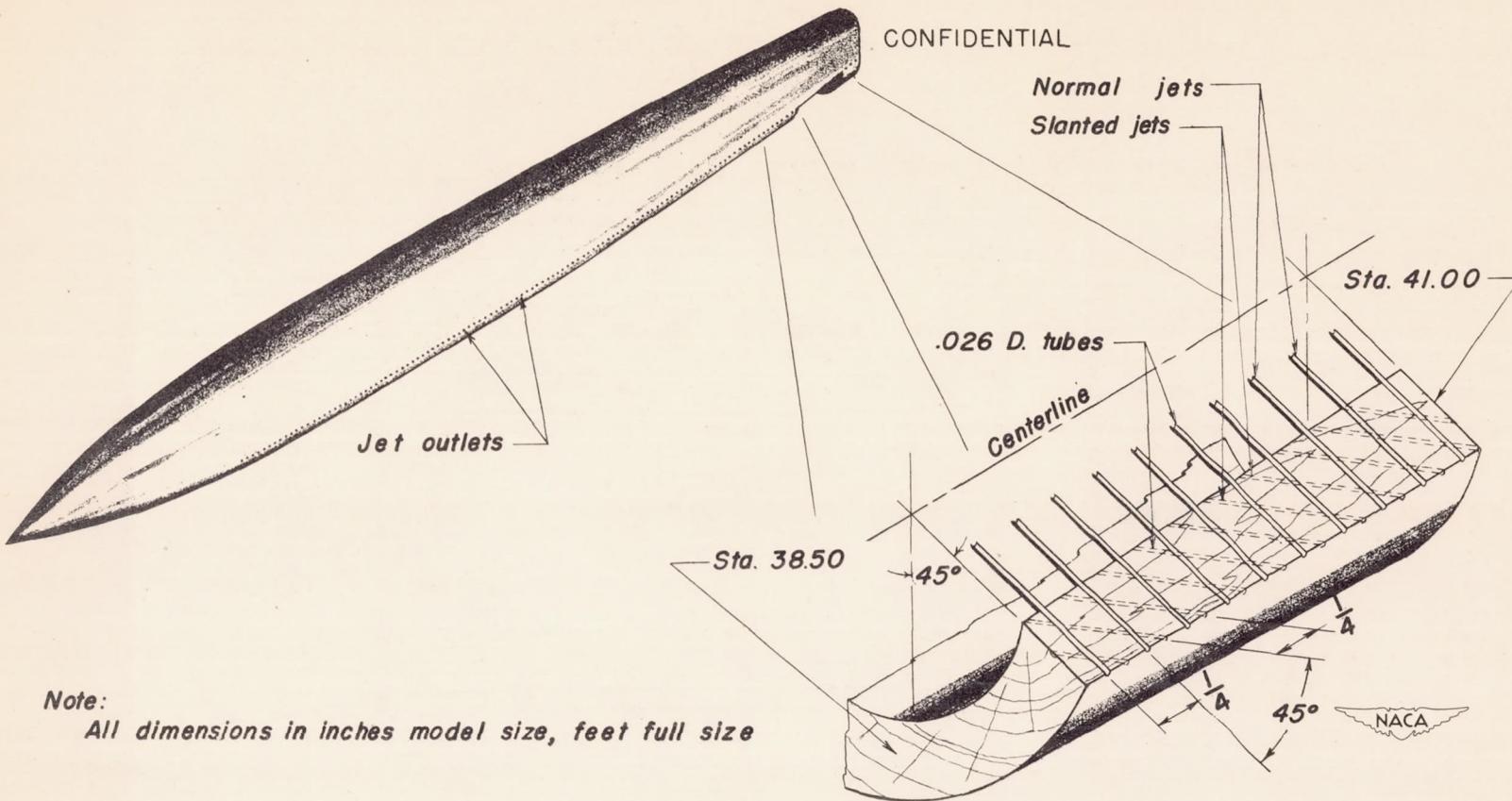
Figure 1.— Exploded view showing the location of jets normal to the center line and jets slanted aft at an angle of 45°.

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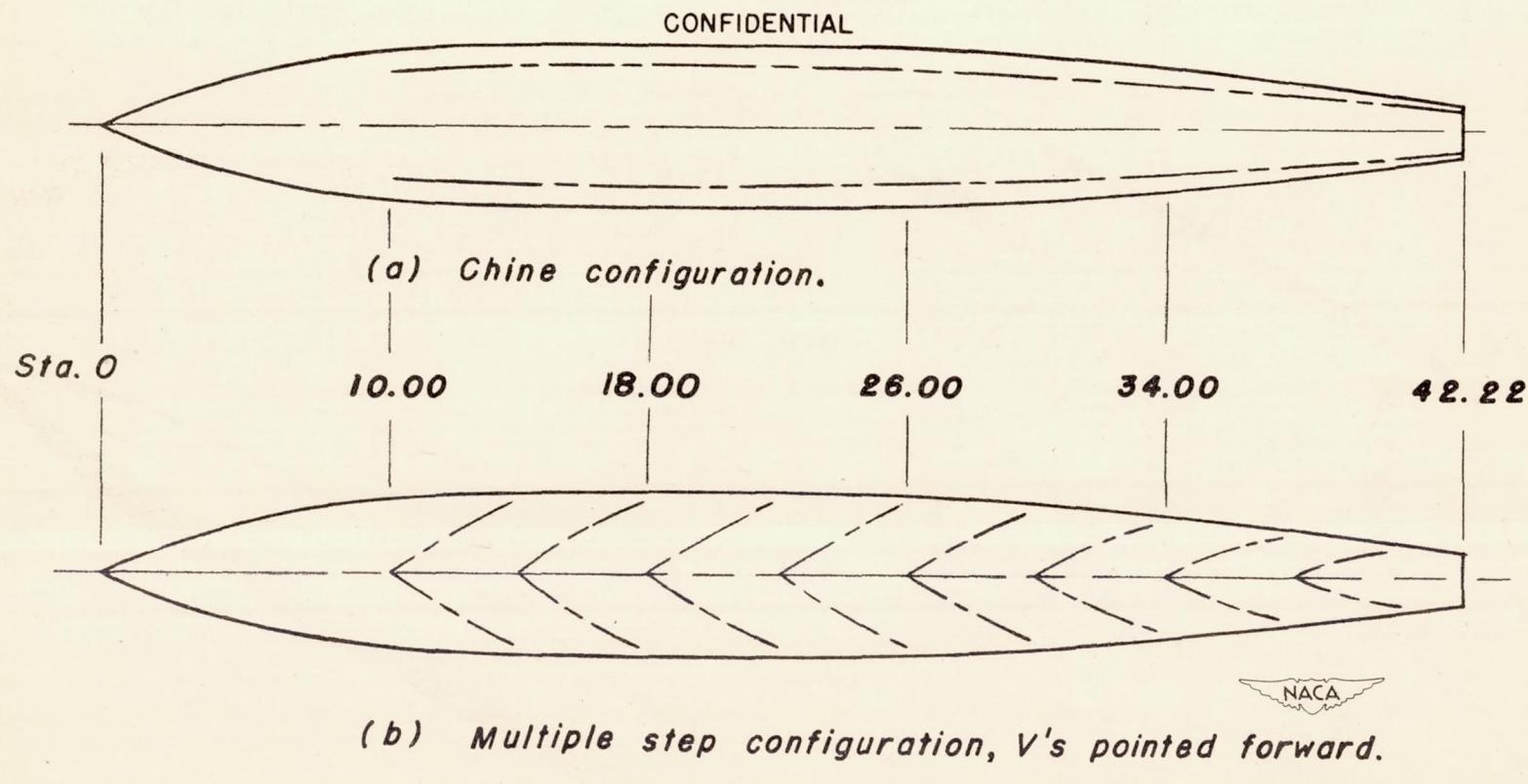
Figure 2.— Bottom views of model showing location of chines and multiple steps.

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(c) Multiple step configuration, V's pointed aft.

Sta. 0   10.00   18.00   26.00   34.00   42.22
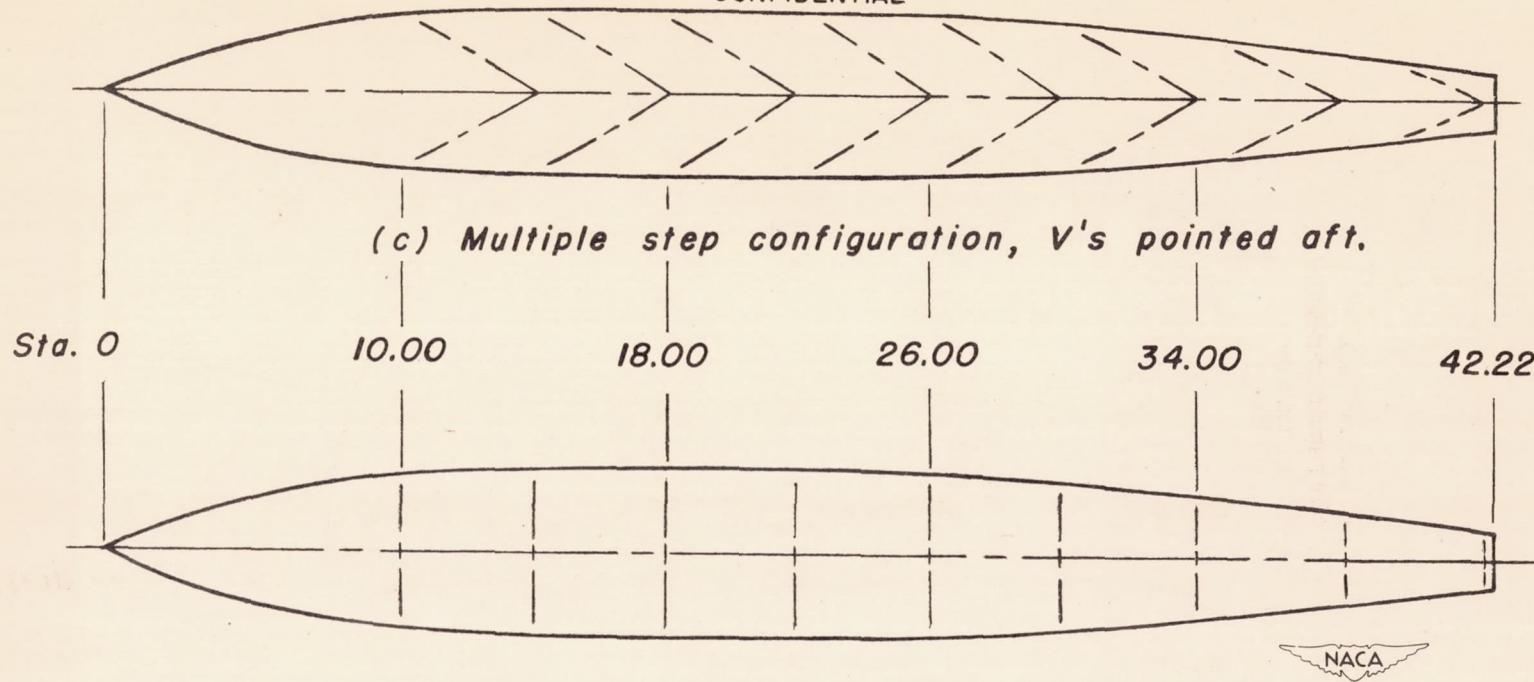
(d) Multiple step configuration, transverse.

Figure 2.— Concluded.
CONFIDENTIAL

Station 0   10.00   CONFIDENTIAL   42.22

Bottom view

Strip

2.50" R

45°   45°

$\frac{1}{16}$"

NACA

Maximum section
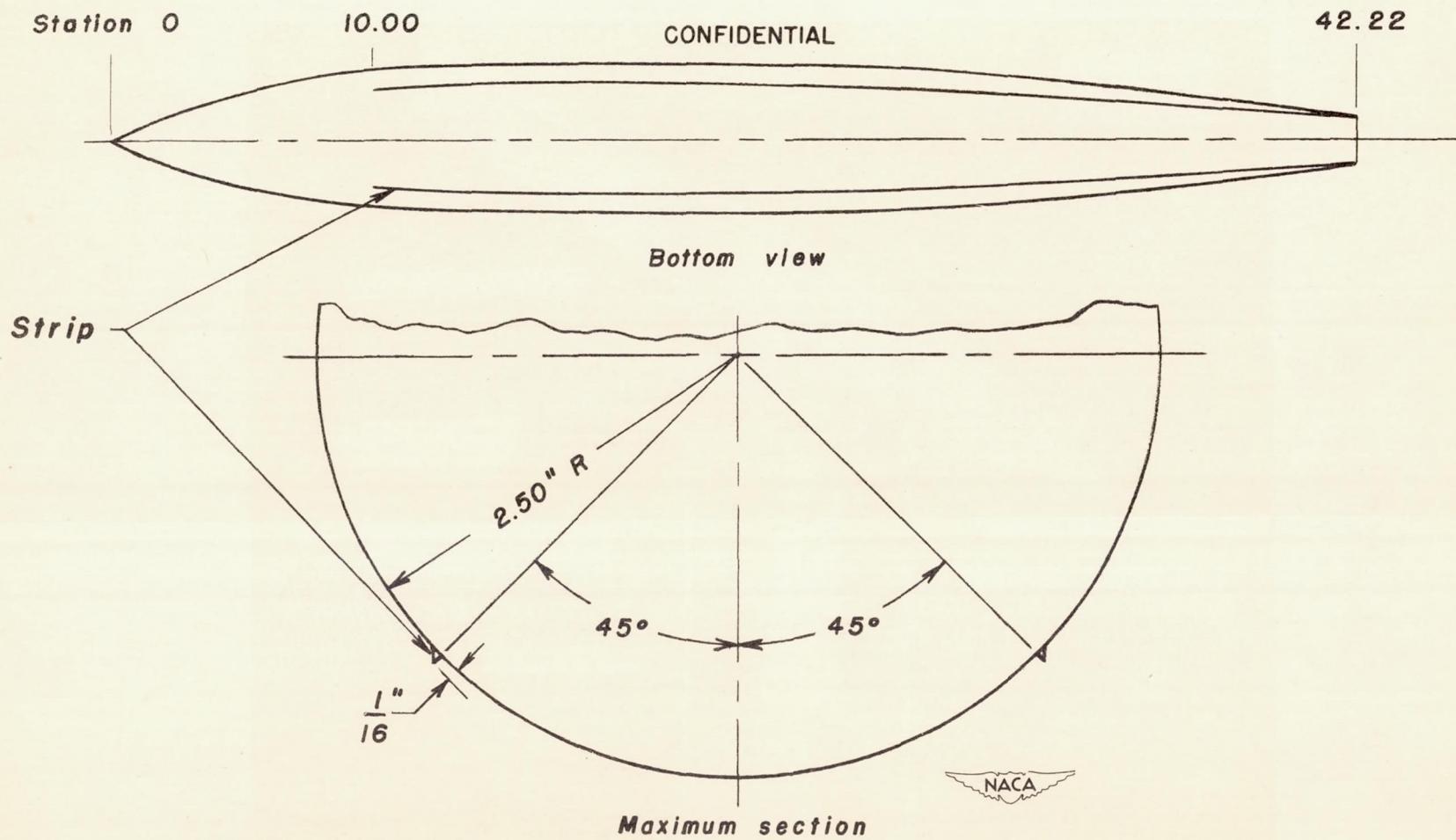
Figure 3.— Size of strips relative to model.
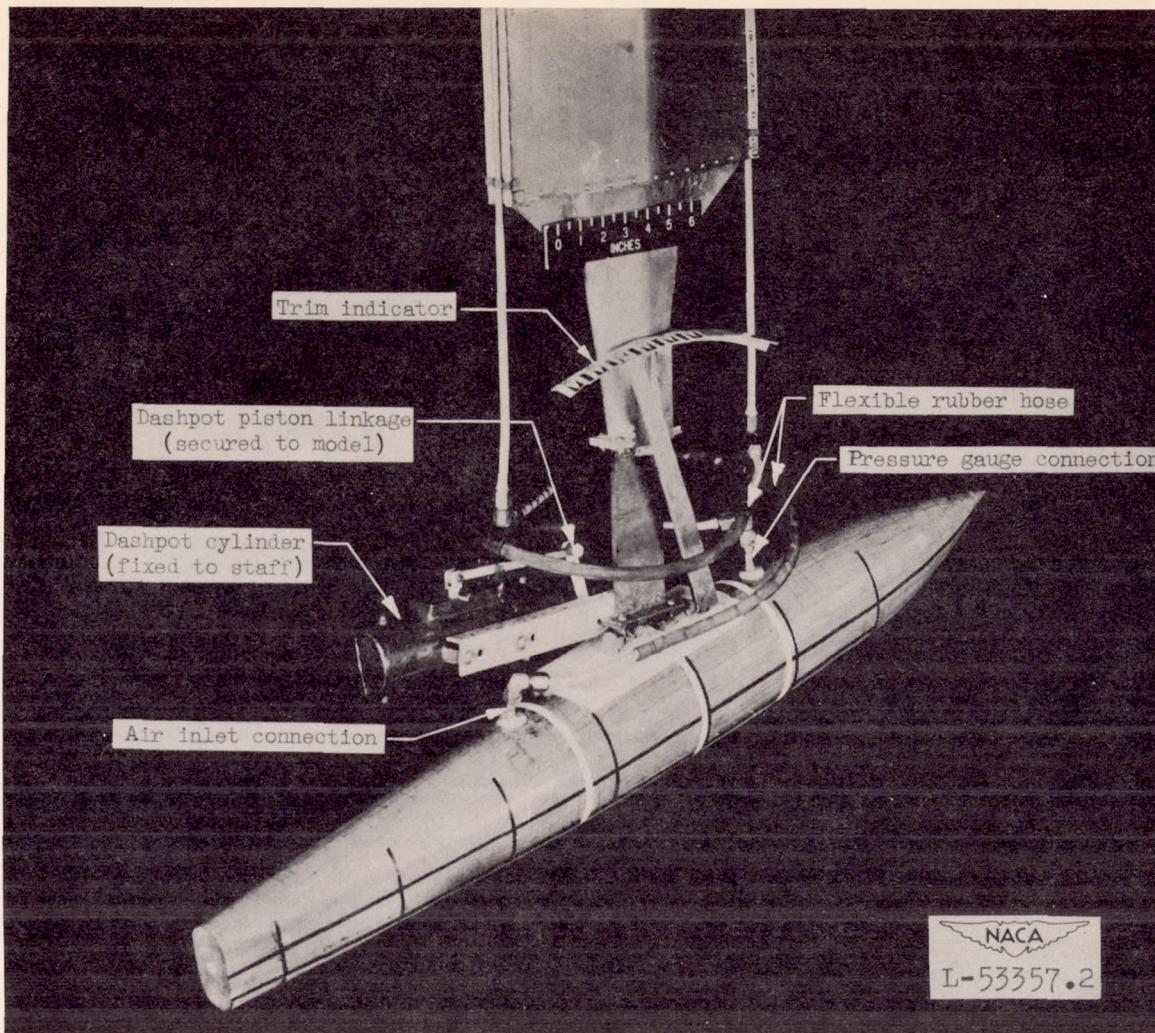
Figure 4.— Model mounted for testing.
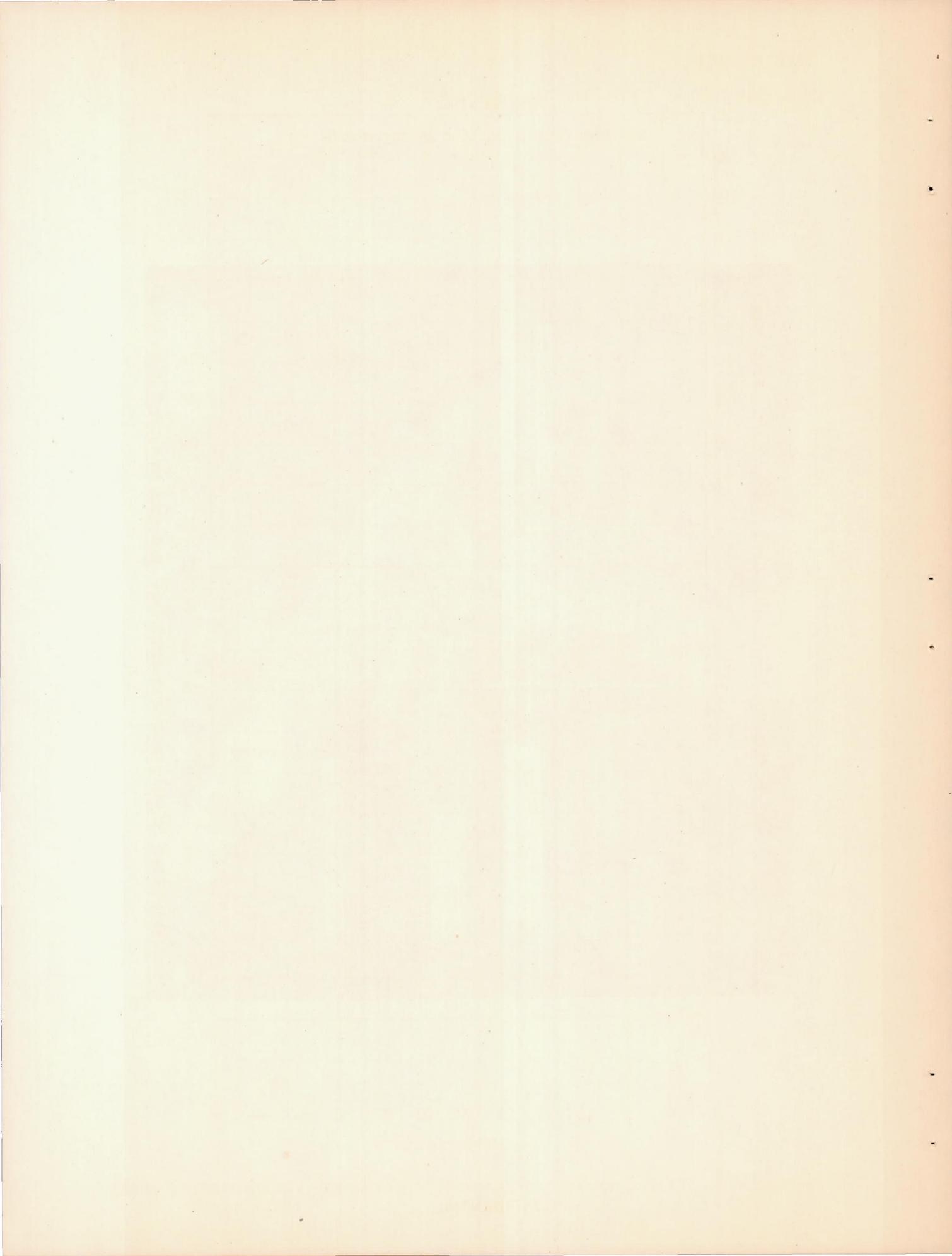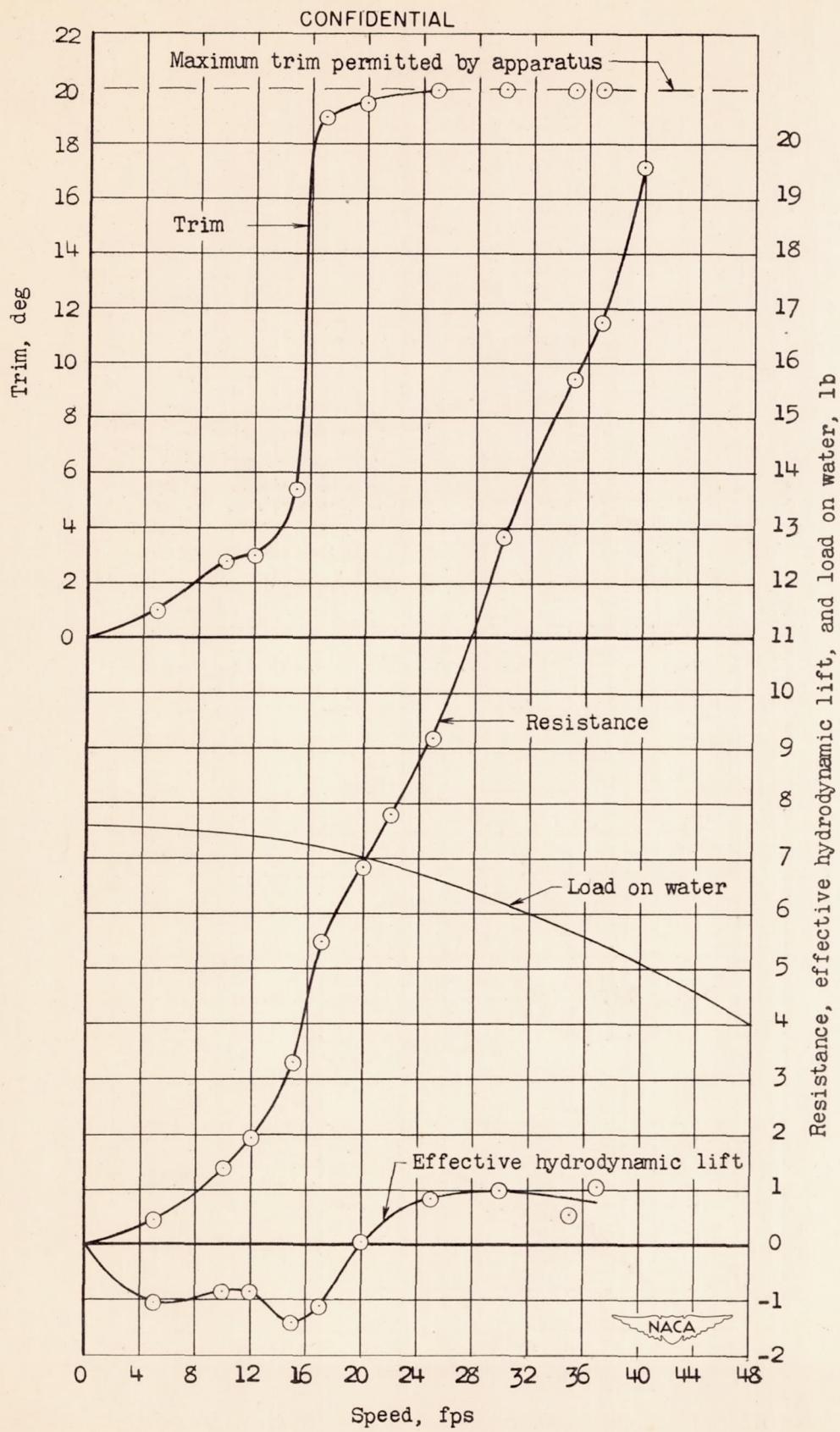
Figure 5.— Hydrodynamic characteristics of basic or unmodified model.
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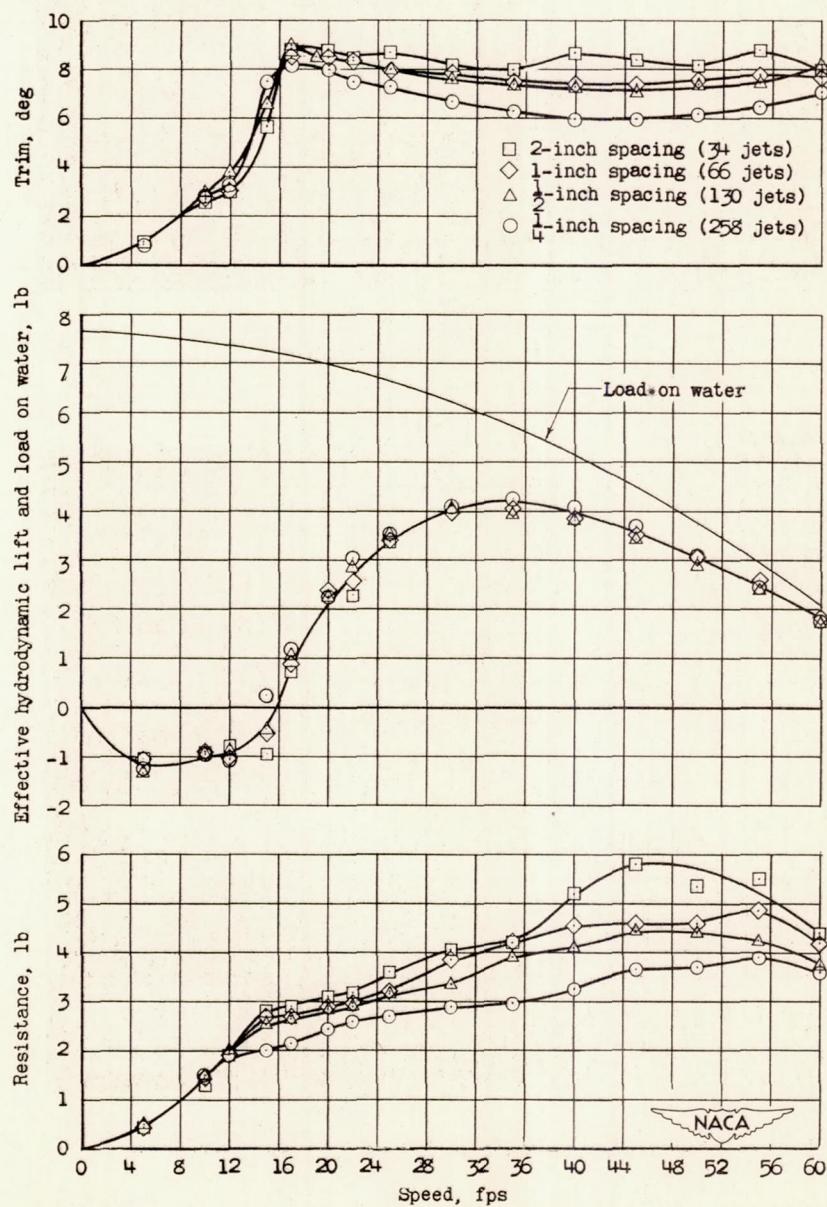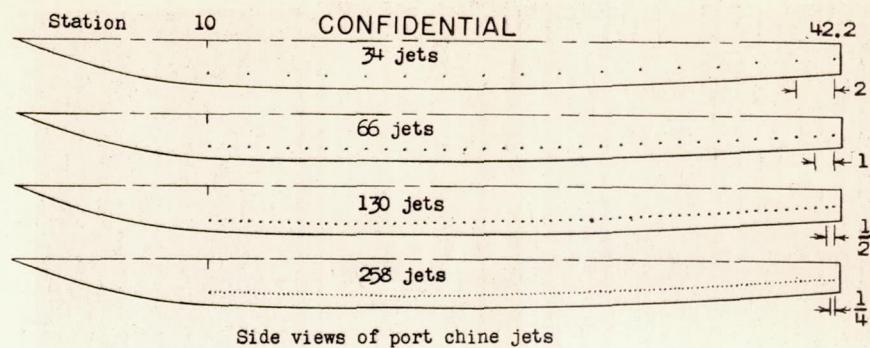
Figure 6.– Effect of jet spacing; chines 32 inches long; jets normal to center line.

(a) 2—inch—spaced jets; trim, 8.0°.
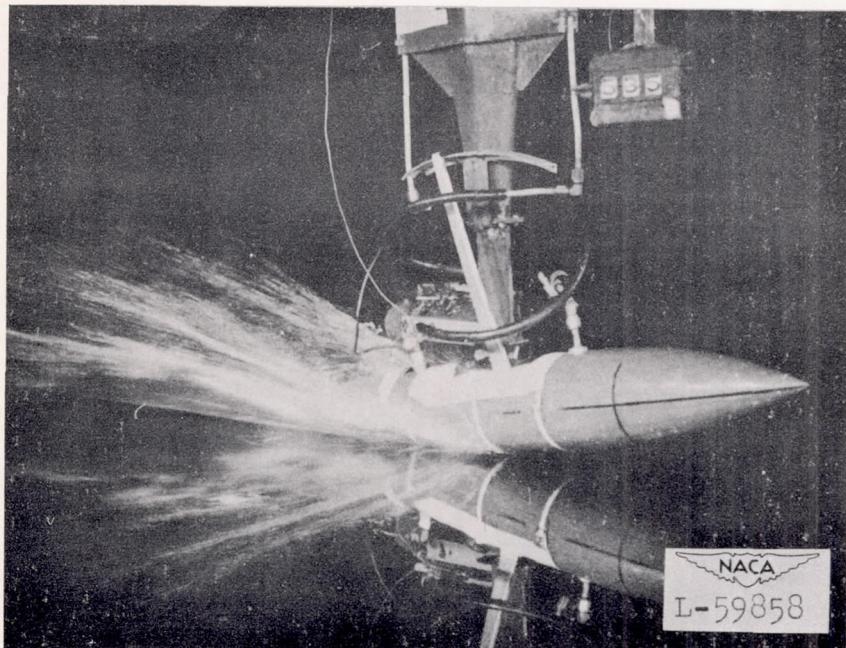
(b) $\frac{1}{4}$— inch—spaced jets; trim, 6.3°.

Figure 7.— Effect of jet spacing at 35 feet per second; 32—inch chines; station 10 to 42.
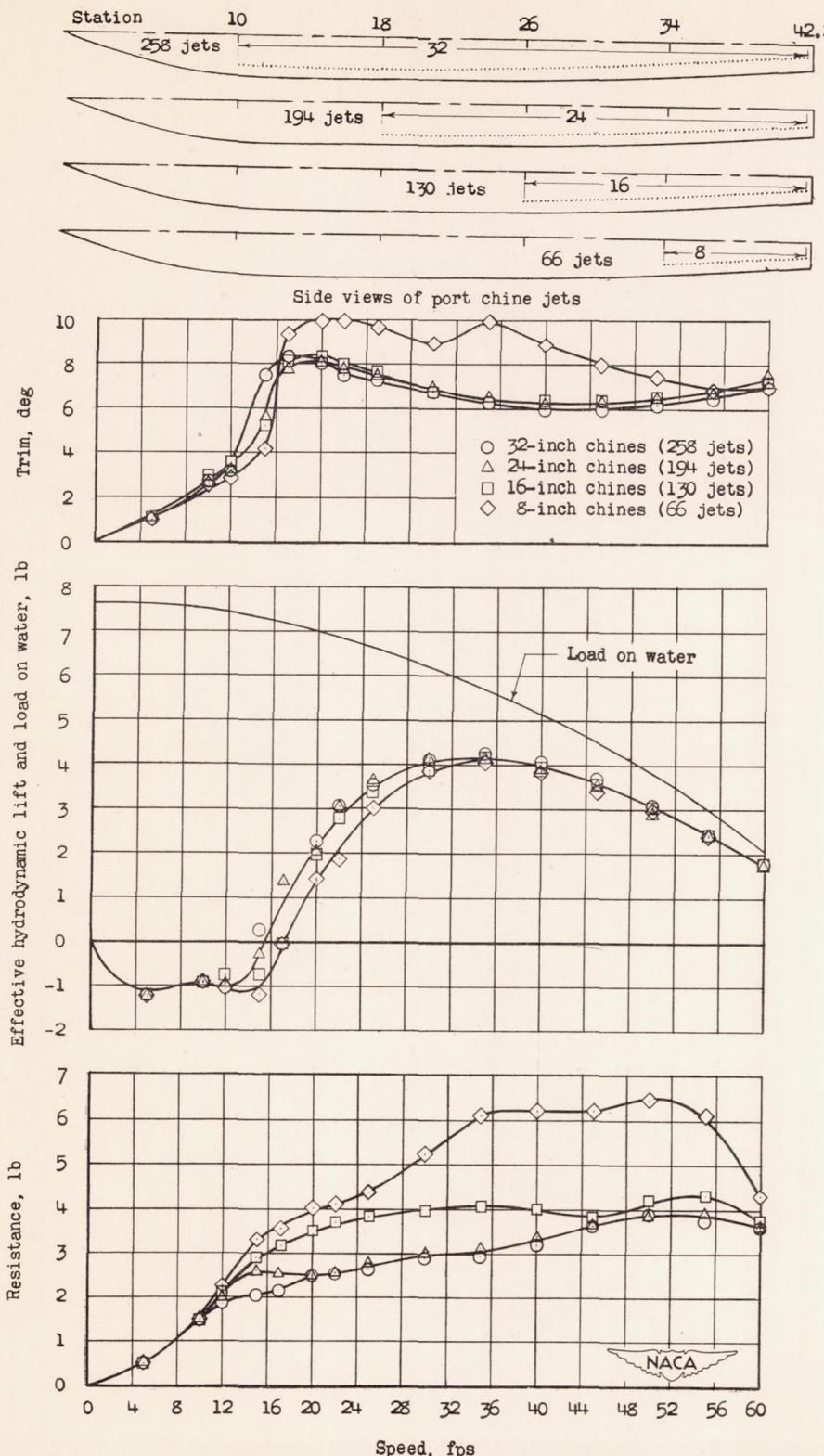
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Figure 8.— Effect of length of jet rows; $\frac{1}{4}$— inch—spaced jets normal to center line.

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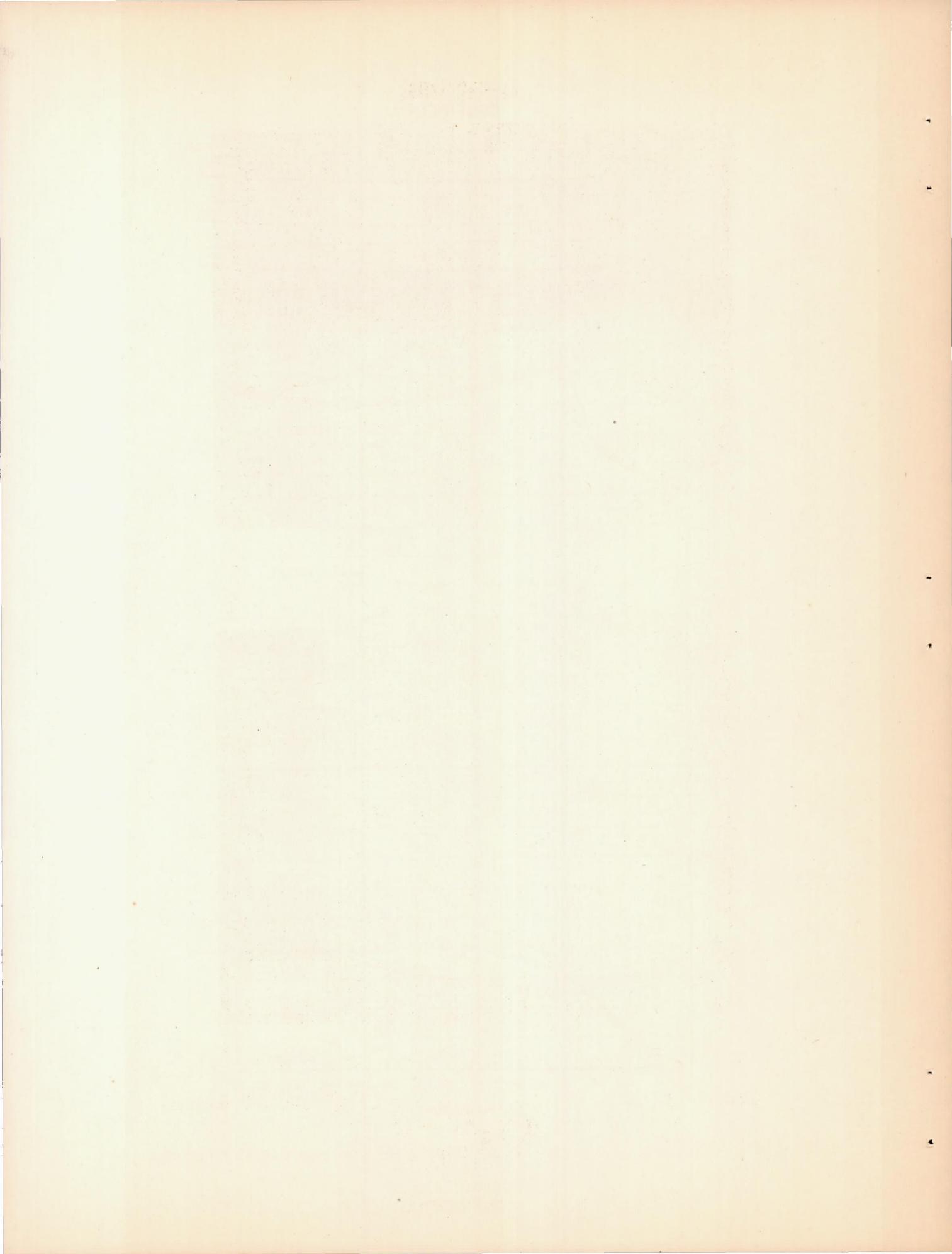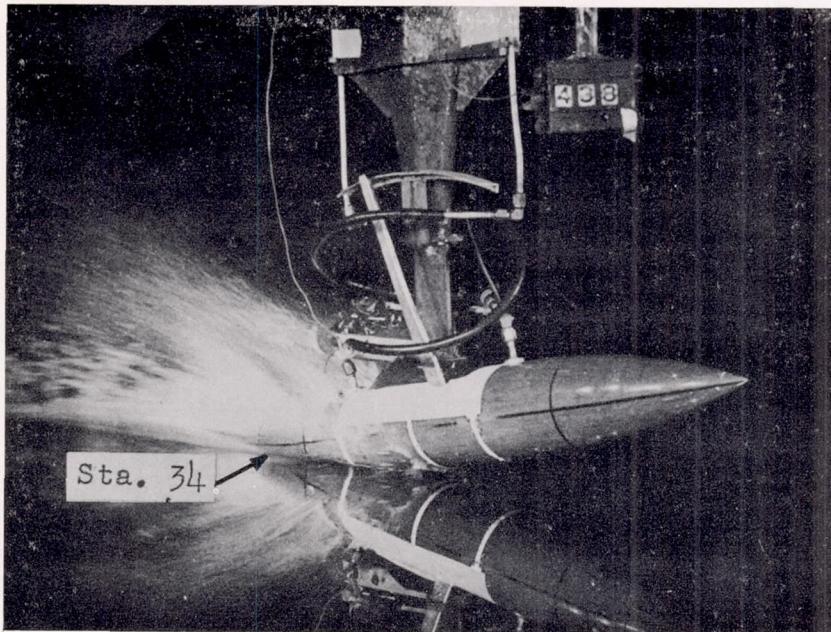
(a) 8-inch long chines; station 34 to 42; trim, 10°
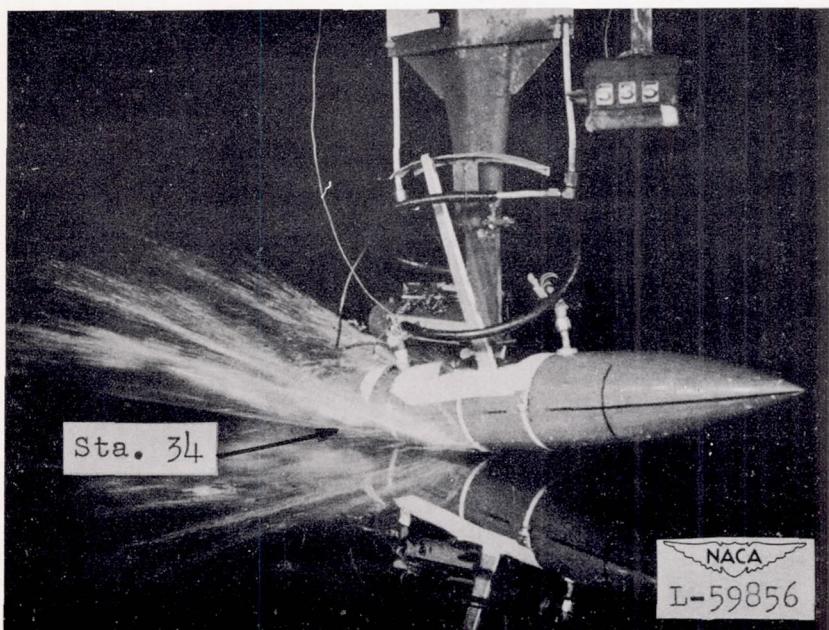
(b) 32-inch long chines; station 10 to 42; trim, 6.3°.

Figure 9.— Effect of length of jet rows at 35 feet per second;
$\frac{1}{4}$—inch—spaced jets.

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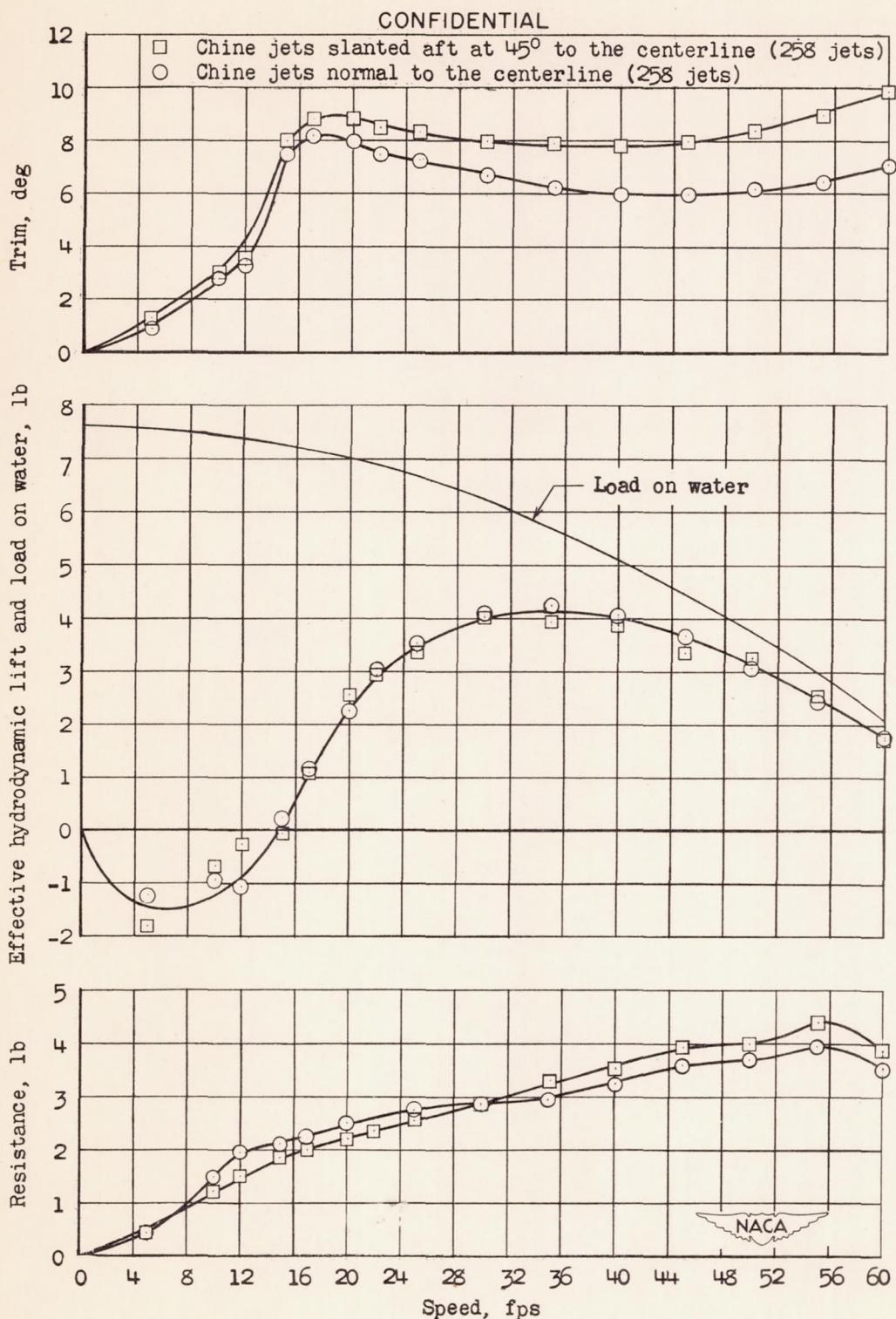
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Figure 10.— Comparison of slanted and straight jets; $\frac{1}{4}$ — inch—spaced jets;

station 10 to 42.

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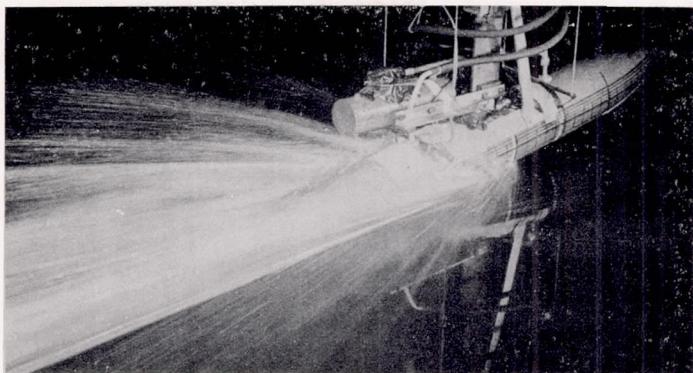
(a) Normal jets; trim, 6.3°.
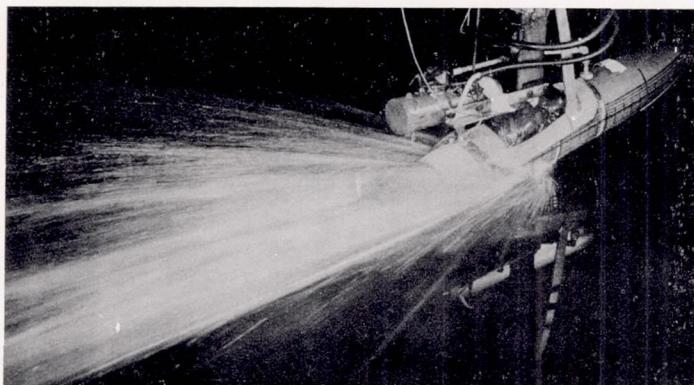
(b) Slanted jets; trim, 7.9°.
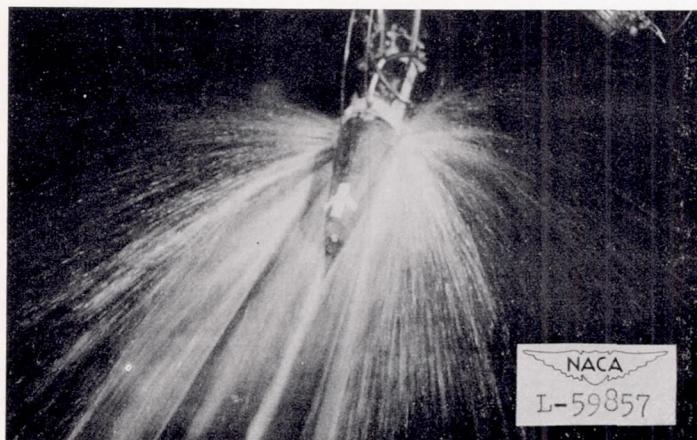
(c) Slanted jets; trim, 7.9°.

Figure 11.— Jets spaced $\frac{1}{4}$—inch apart; station 10 to 42; 35 feet per second.
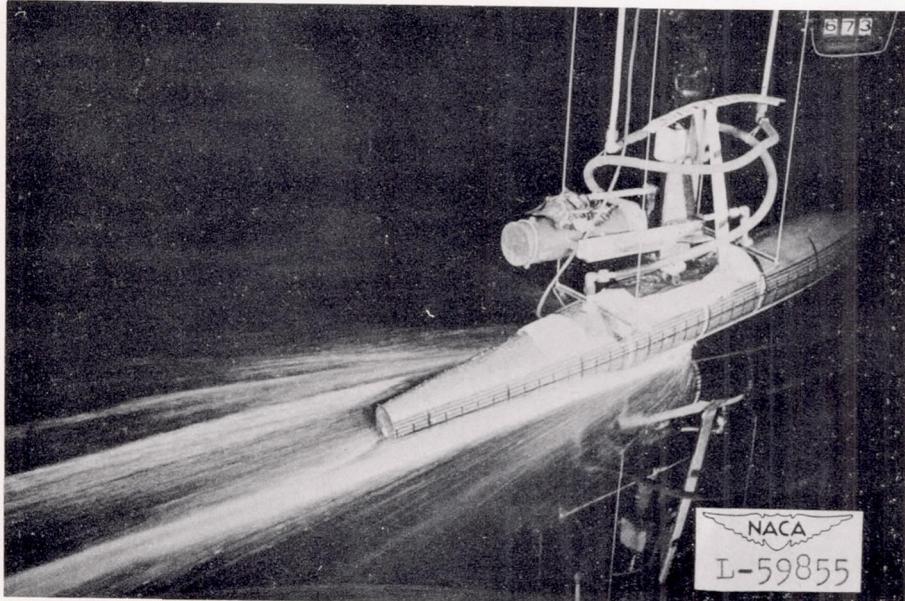
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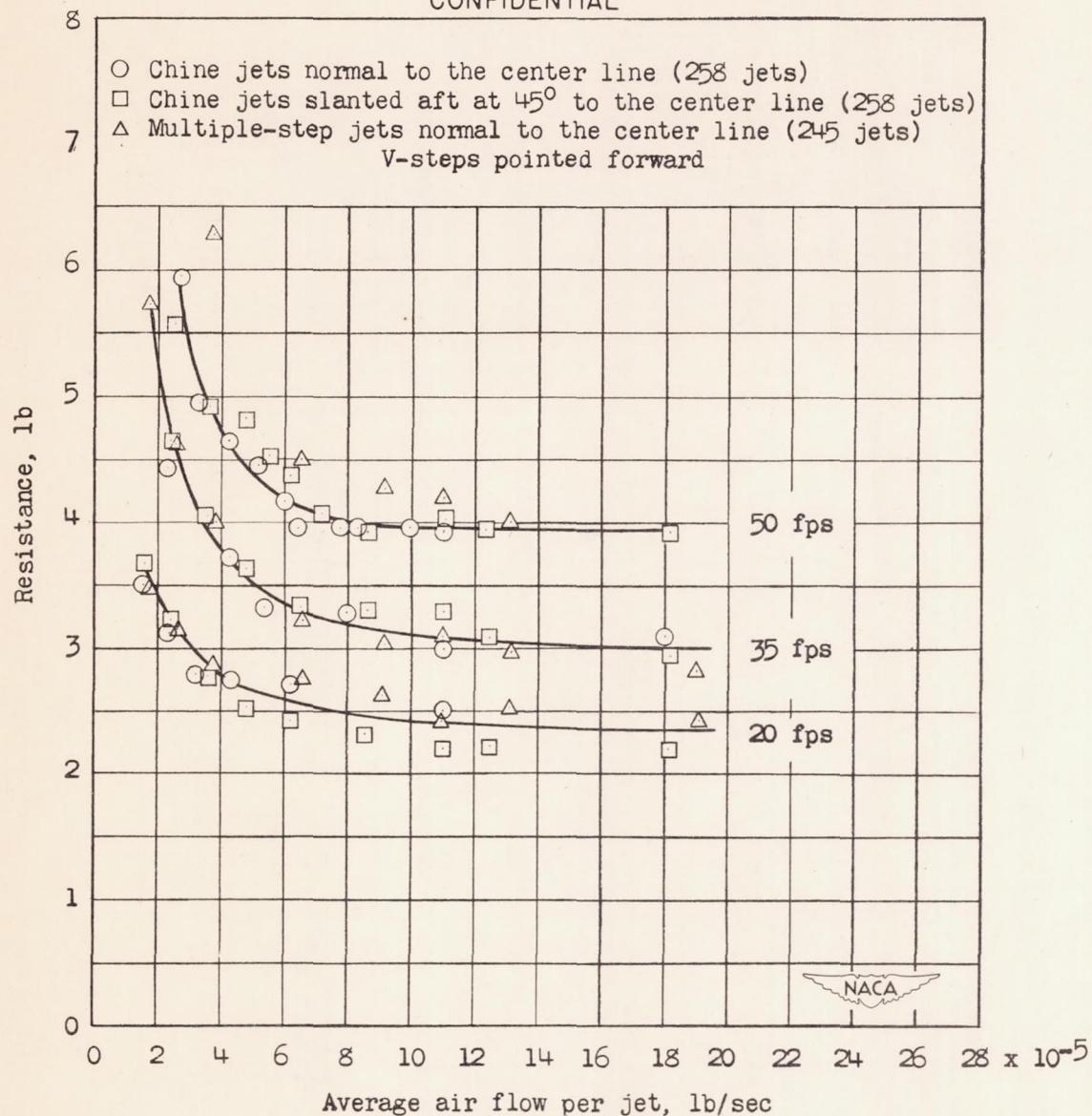
Figure 12.— Effect of quantity of air flow.
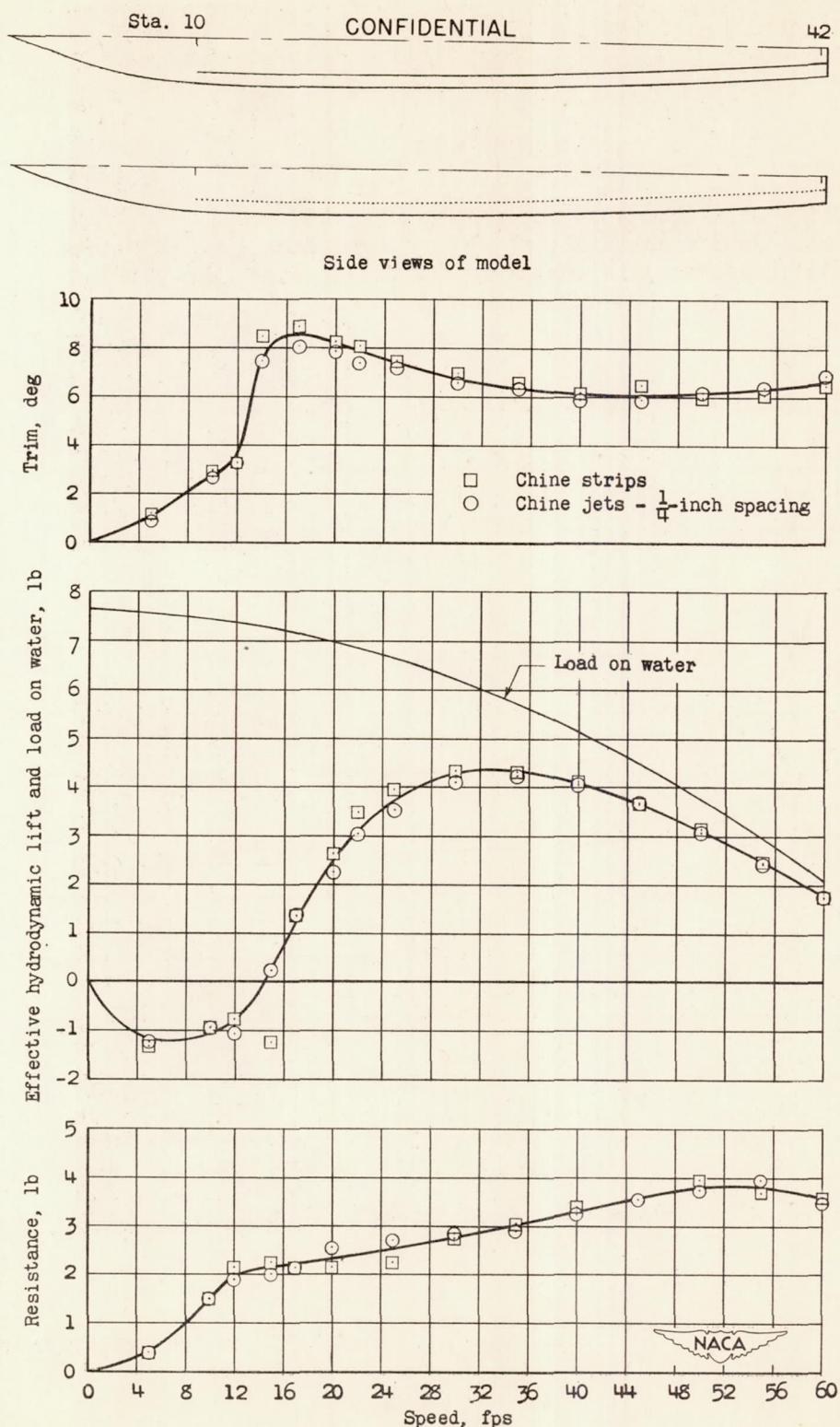
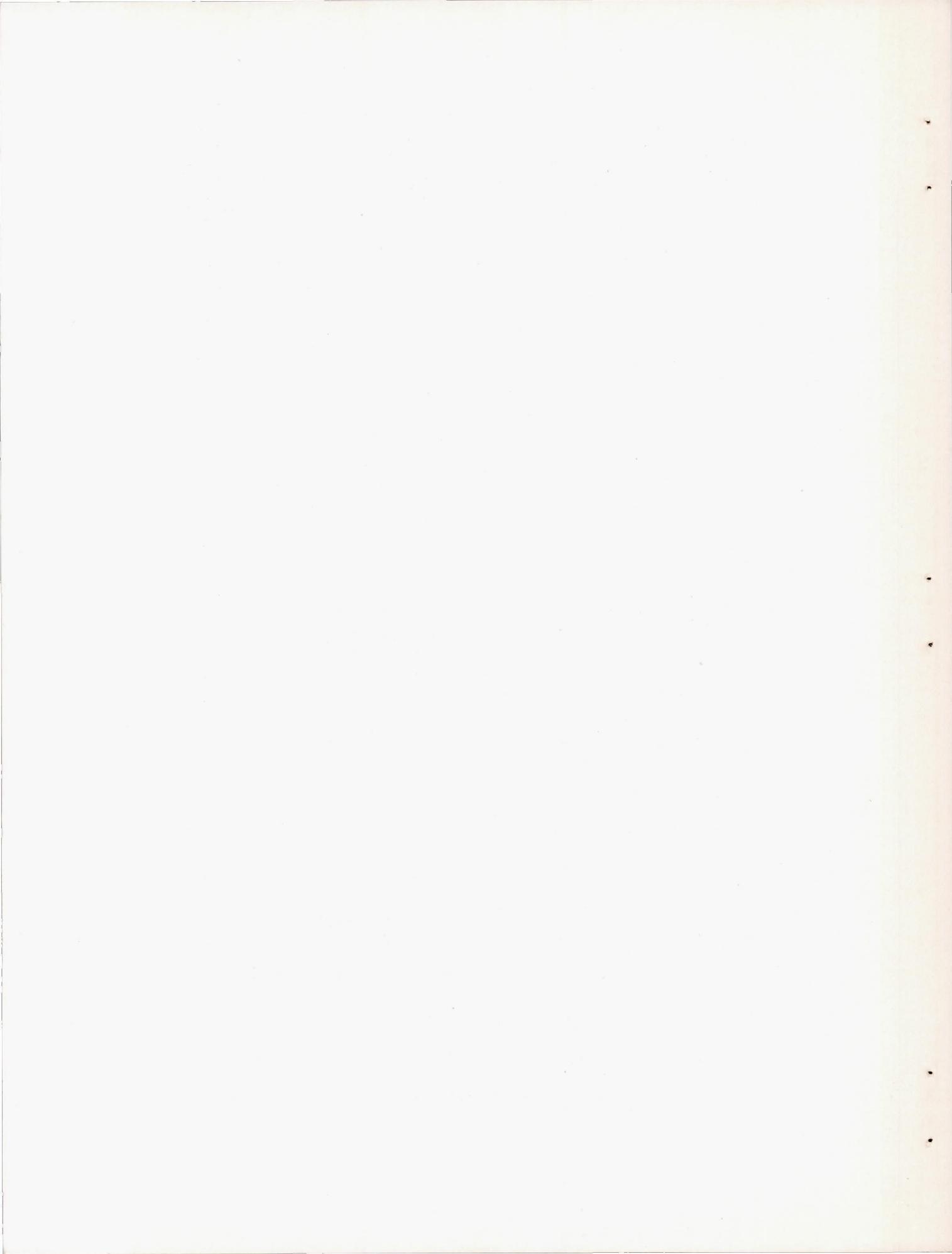Figure 13.— Comparison of strips and jets simulating chines; station 10 to 42.
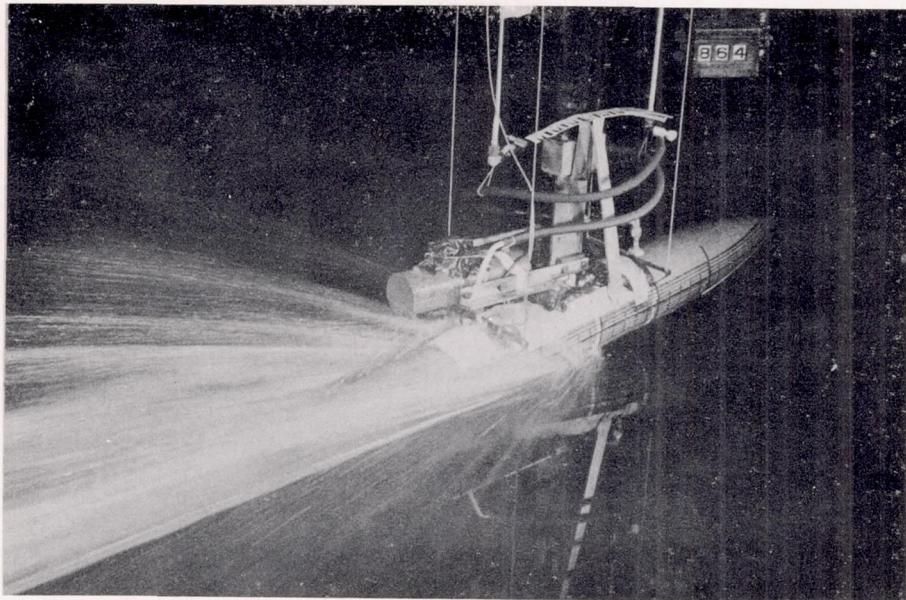
(a) $\frac{1}{4}$ – inch–spaced jets; trim, 6.3°.

(b) Strips; trim, 6.6°.

Figure 14.– Comparison of jets and strips at 35 feet per second; simulated chines; station 10 to 42.
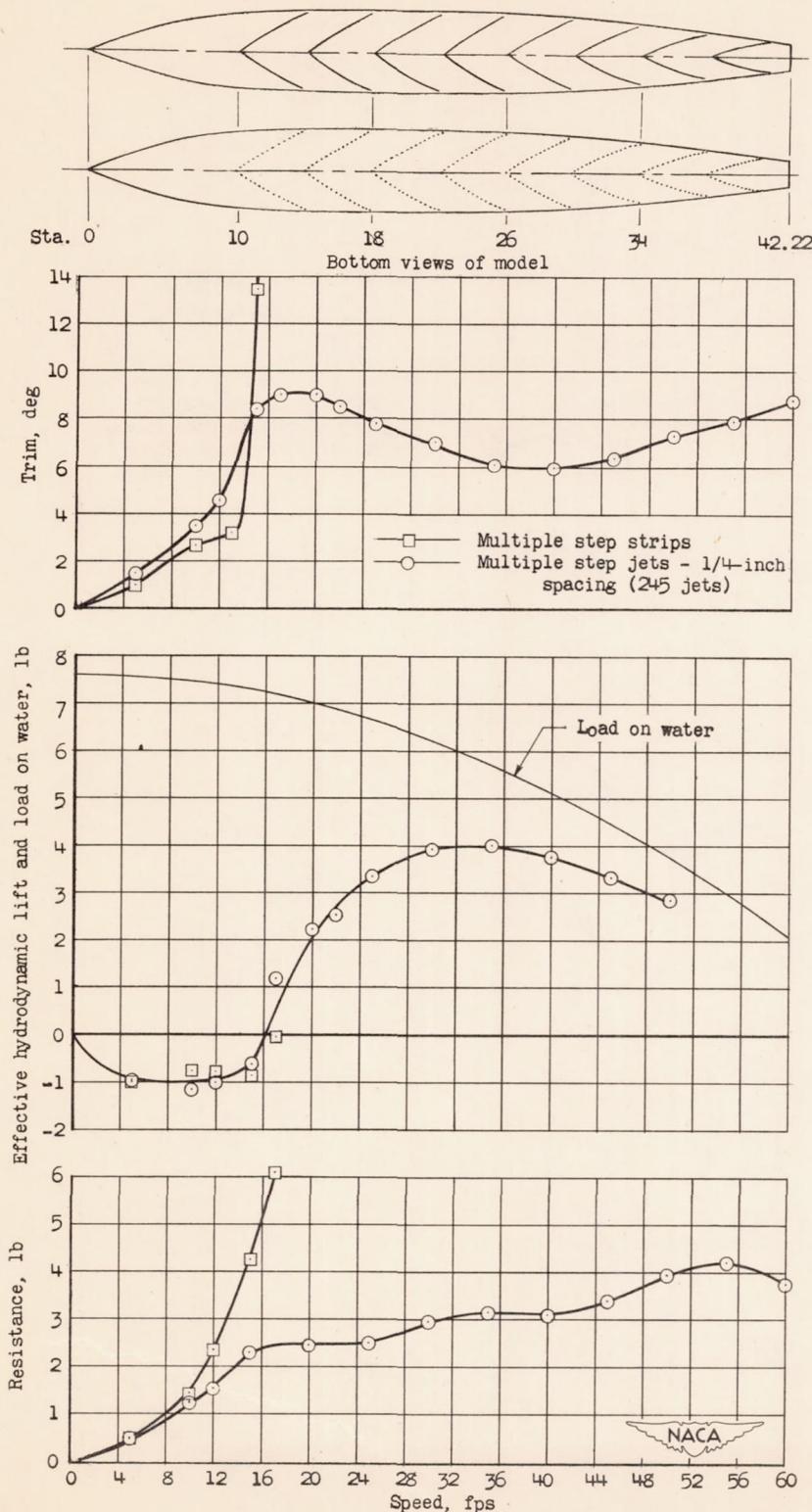
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Figure 15.– Comparison of jets and strips simulating multiple steps.
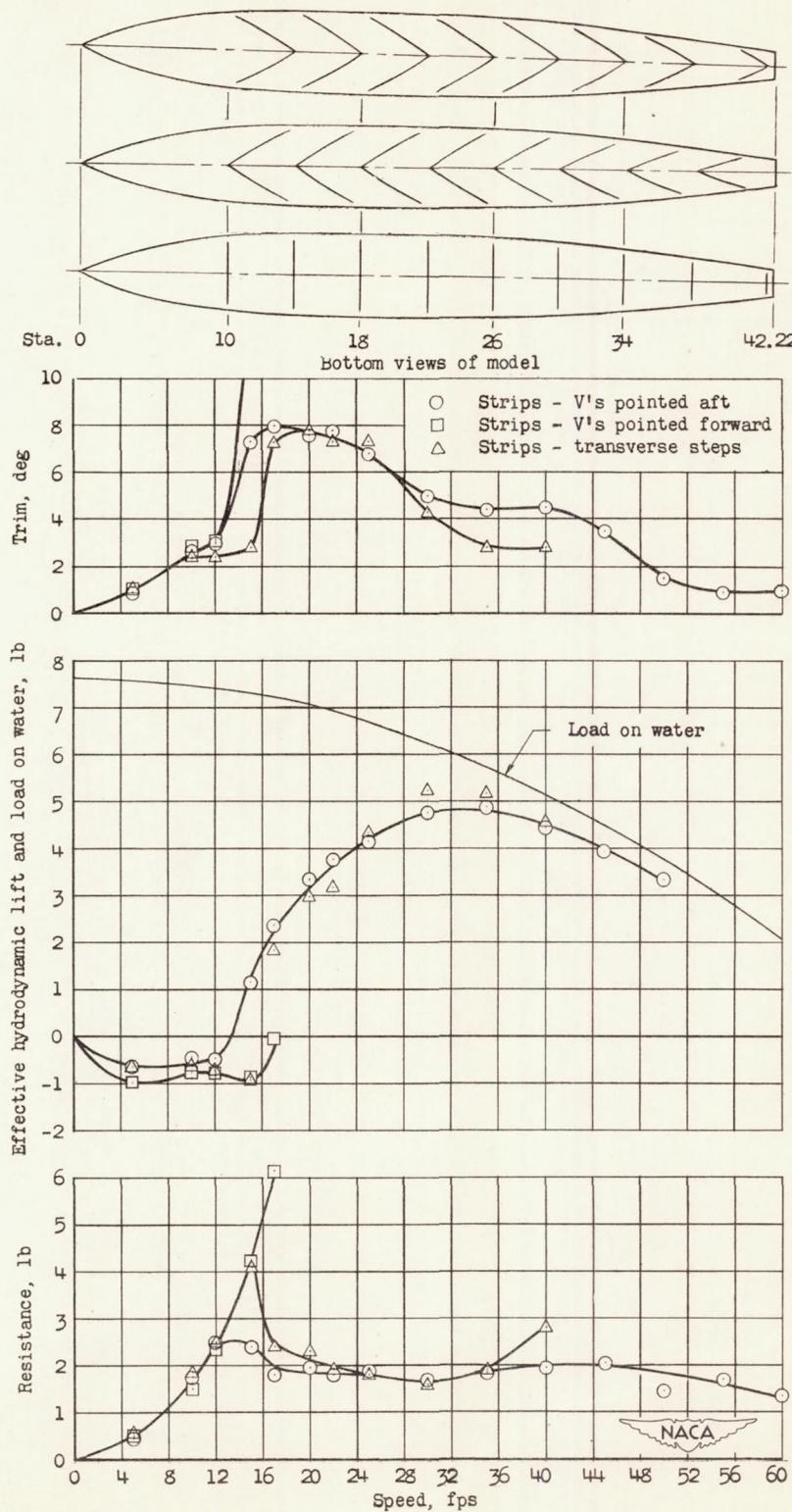
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Figure 16.— Comparison of strips simulating multiple steps.